PSB RF system Upgrade
Availability studies

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Acknowledgments: Andrea Apollonio, Michael Jonker, Mauro Paoluzzi.

Outline

- The PSB RF System
- Availability and Reliability studies
- Isograph model
  - Isograph Availability Workbench
  - PSB RF System model
  - Input data
  - Assumptions
  - Results
  - Conclusions
- Analytical model
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  - Sensitivity analysis
  - Preliminary results
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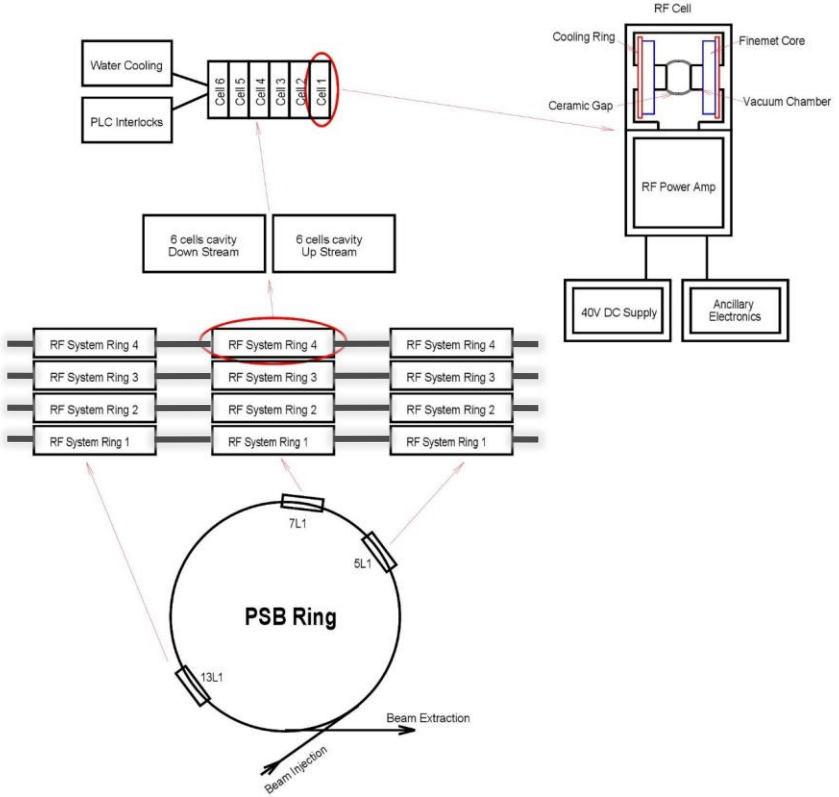
PSB RF System

- The **Proton Synchrotron Booster (PSB)** is made up of four superimposed synchrotron rings that receive beams of protons from the linear accelerator.
- Each synchrotron ring has its independent RF system.
- The **PSB RF system is upgraded** in the framework of the LIU (LHC Injectors Upgrade) project.



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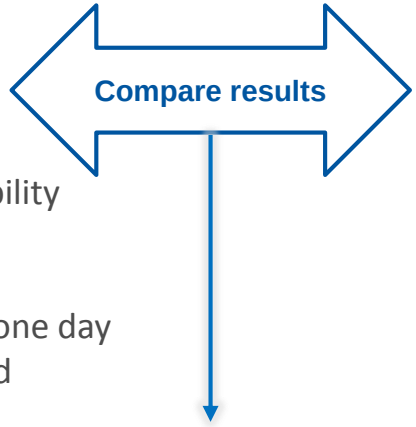
Availability and Reliability studies

Scope:
Dependability studies to assess the achieved RF system availability and reliability.

Two approaches:

Monte Carlo Simulations

- Commercial software: Isograph Availability workbench.
- Each simulations run takes more than one day (due to the amount of components and redundancy).



Analytical calculations

- Boolean system probability theory.
- Calculations take less than 5 minutes.

Validate the analytical model ⇨ Faster method for availability calculations

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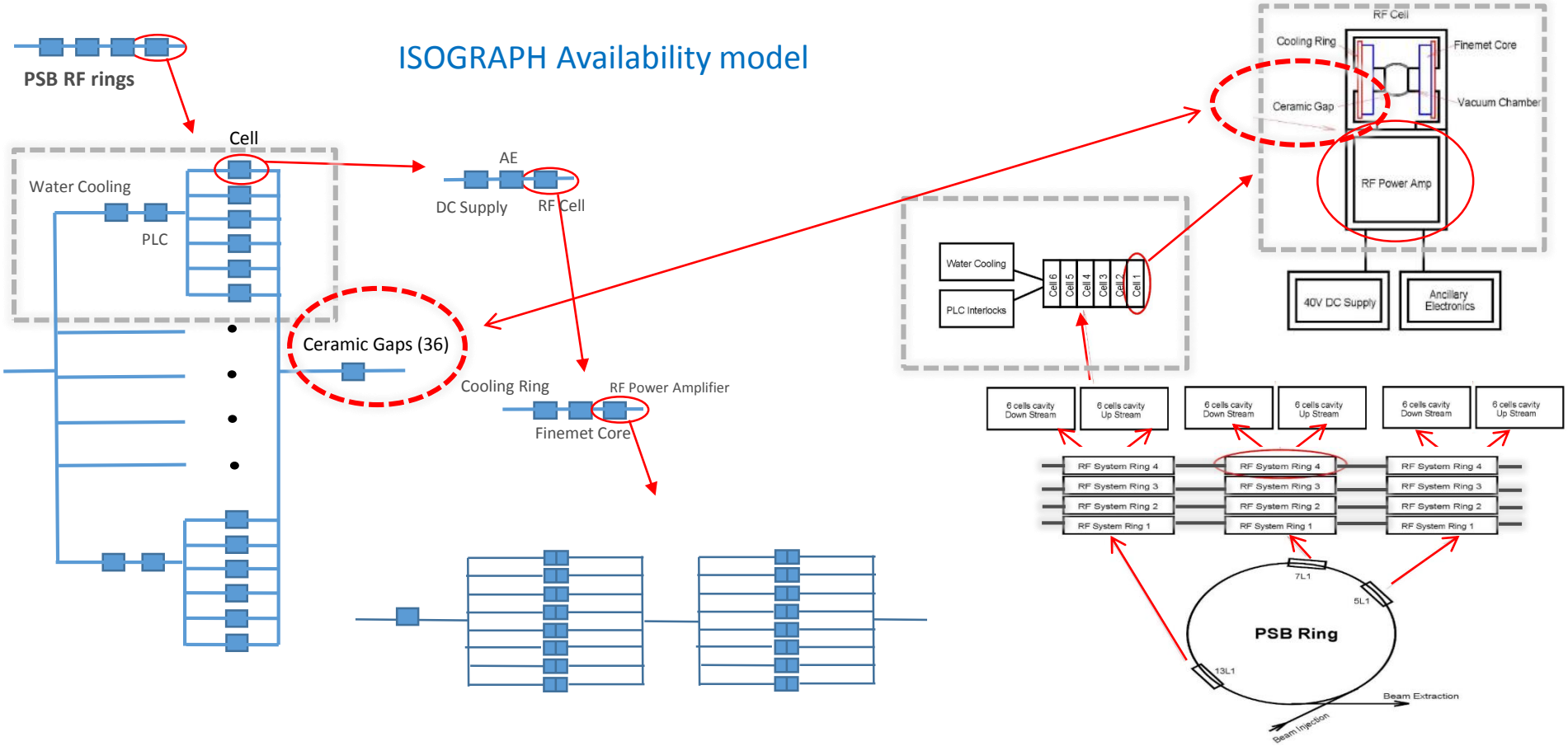
ISOGRAPH® Availability workbench

- Availability simulation software.
- Performs Monte Carlo Simulations.
- Used to optimize maintenance and spares policies and predict system availability.
- Reliability Block Diagrams (RBD) are used to model system dependencies and behaviour in case of failures.
- The RBD is made of blocks and nodes connected in parallel or series.
- A voting strategy is defined in case of redundant components (blocks).
- A Failure mode is assigned to each block.
- Different Maintenance Strategies can be defined.

ISOGRAPH Availability model



Input Data- **MTTF**

Component	No. of components in the system	MTTF (years)	MTTF (h)	Data source
Water Cooling	24	10x24	2102400	Expert experience. Machine made up of 24 components failed ones in 10 years.
PLC Interlocks	24	22	200000	PLC MTTF=Its Power Supply MTTF Manufacturer data: Values from 200.000 to 980.000 hours
DC Supply	144	5	43800	Expert experience.
Ancillary Electronics	144	5	43800	Expert experience.
Cooling Ring	144	40x10x50	175E+6	Expert experience from PS. 1 ring failed in 40 years, 50 rings per cavity, 10 cavities
Finemet Core	144	10000/2	43.8E+6	Expert experience from various machines. One Finemet Core failed once each 10.000 years. The component is made up of two Finemet Cores
Ceramic Gaps (36)	4 (144/36)	20000/36	4.8E+6	Expert experience from various machines. One Ceramic Gaps fails ones each 20.000 years
Mosfets pair	4608/2	18600000/2	8.15E+10	Manufacturer data
Mosfets Driver	144	18600000	1.63E+11	Manufacturer data

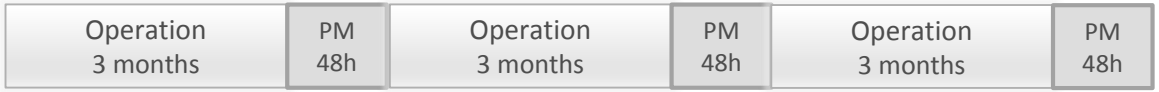
Input Data – **Maintenance times**

Component	Corrective Maintenance(h)	Spares Available	
		Best Case (100%)	Worst Case
Water Cooling	2+4	24	2 (10%)
PLC Interlocks	2+4	24	2 (10%)
DC Supply	2+4	144	36 (25%)
Ancillary Electronics	2+4	144	4 (3%)
Cooling Ring	72	144	24 (17%)
Finemet Core	72	144	26 (18%)
Ceramic Gaps	72	-Not possible-	1 (%25) – (28/36)
Mosfets pairs/Drivers	2+4	10000	1382 (%30)

Operation / Planned Maintenance period 3 months (2190h)

Planned Maintenance time 48 hours

Lifetime **6714 h (3 Operation phases and 3 PM phases)**



Assumptions

CORRECTIVE MAINTENANCE:
Maintenance done when the RF system is not available any more due to components failures.

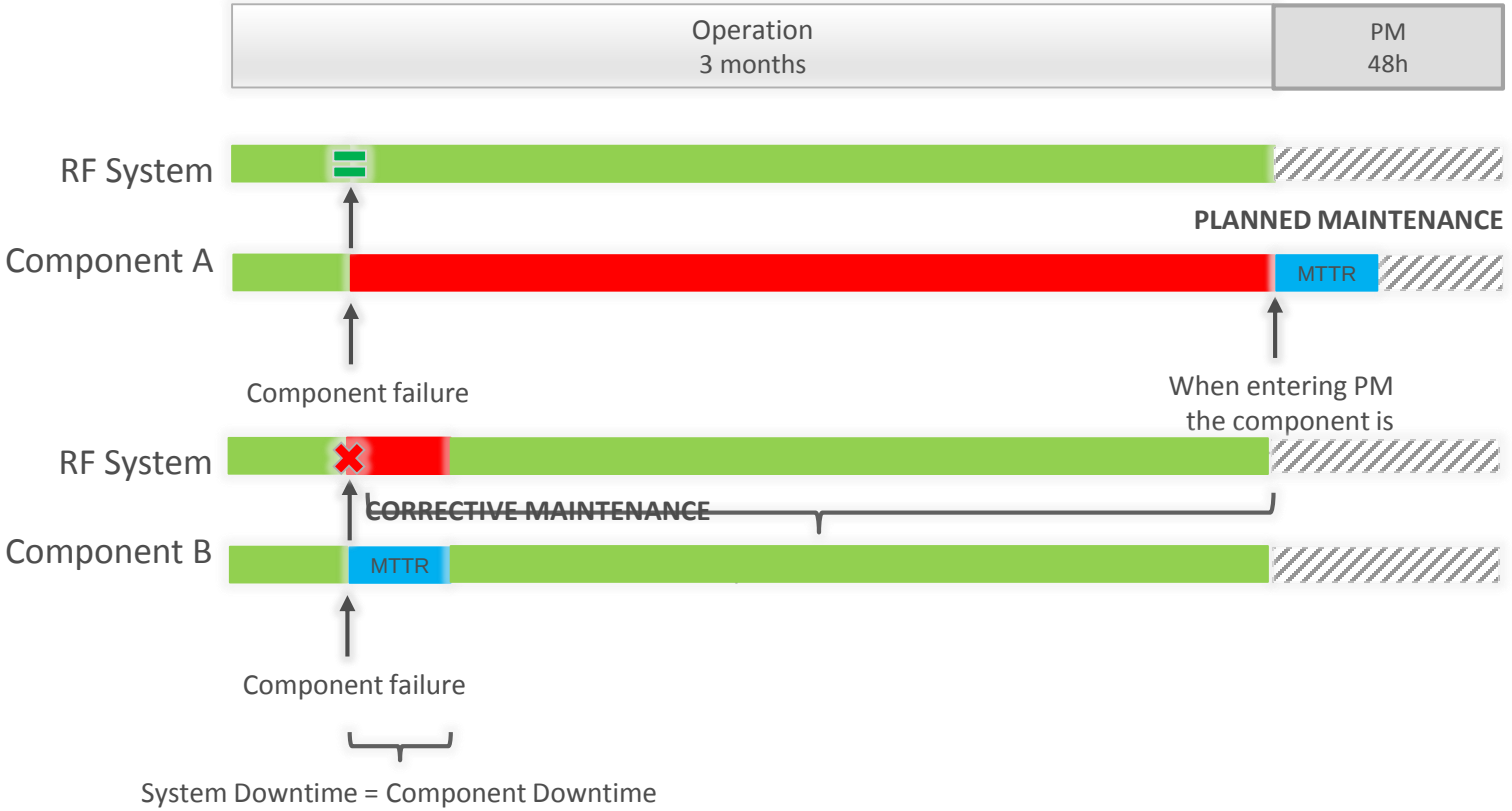
- ❑ CM in all the failed components.
- ❑ Components are non-operational* when doing CM.

PLANNED MAINTENANCE:
Scheduled maintenance at predefined time.

- ❑ Components are non-operational* when doing PM.
- ❑ PM time is not taken as RF system downtime.

* Non-operational : The component can not experience failures

Assumptions



Failures=0
Downtime=0

Failures=1
Downtime >> MTTR

Failures=1
Downtime=MTTR

Failures=1
Downtime = MTTR

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Results – **PSB RF System** Availability predictions

Availability = Availability is defined as the ratio between the operational time and total time.

No. of system failures	Downtime (h)	MTBO(h)	MTTR(h)	Mean Availability	Availability at Lifetime
1.077	**6.7**	**6234.3**	**6.2**	**99. 9%**	100%

MTBO	Mean time between consecutive outages
MTTR	Mean time to restore the system after an outage
Mean Avail.	Expected fractional time the system will be in service
Avail. at lifetime	Prob. the system will be in service at the end of each lifetime.
1 run	1000 simulations of 1 year

Failure = Outage

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The system is expected to fail once during operation due to components failures.

MTBO	Mean time between consecutive outages
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Downtime and MTTR of the system mainly **correspond to the repair time** of components with repair time 6 hours.

Later, will be shown that components causing system failure have repair times of 6h.

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The mean availability of the system is 99.89%

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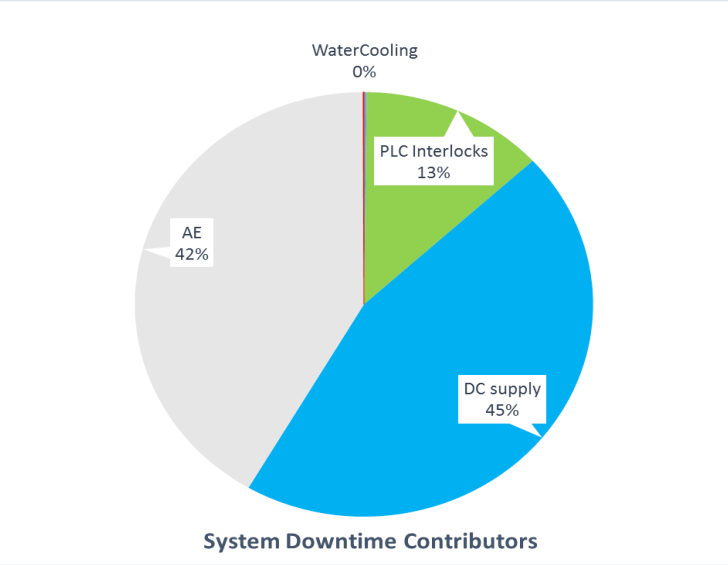
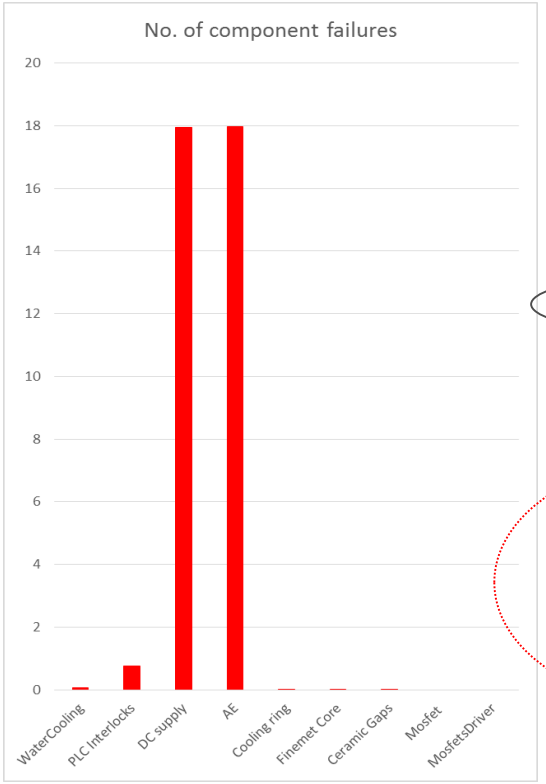


Contributors to system downtime:

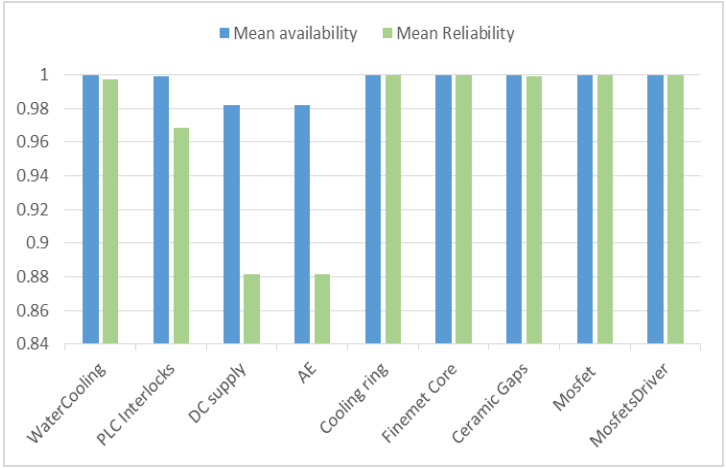
- DC Supply and Ancillary Electronics (86%)
- PLC Interlocks (13%)
- Water Cooling (0.2%)
- Ceramic Gaps (0.05%)

Results – PSB RF System **components** Availability predictions

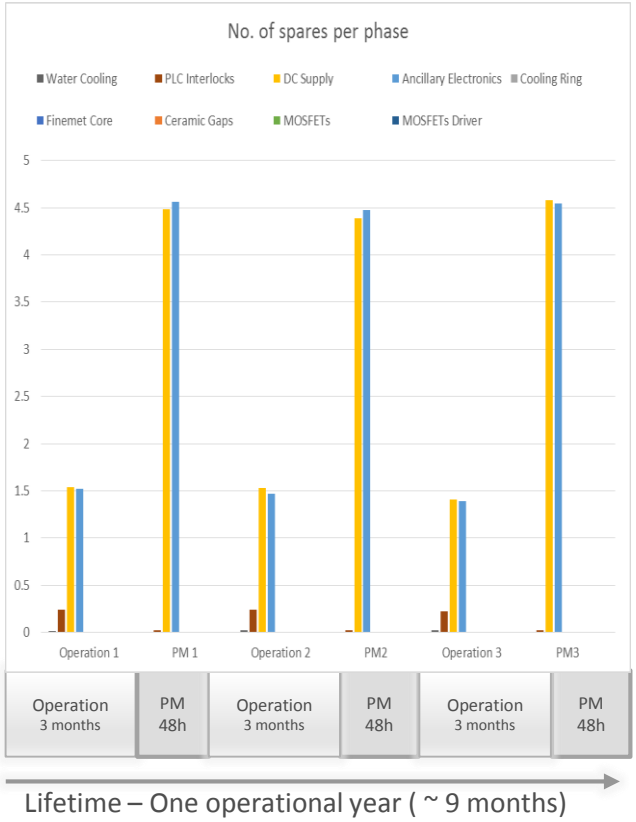


Component	No. of failures	MDT per failure (h)	MTTR
MOSFETs Driver	0	0	6
MOSFETs	0	0	6
Ceramic Gaps	0.003	72	72
Finemet Core	0.02	1079.3	72
Cooling ring	0.004	980.6	72
Ancillary Electronics	**18**	**954.1**	6
DC Supply	**18**	**954.1**	6
PLC Interlocks	**0.76**	**203.03**	6
Water Cooling	0.06	240.2	6

- Components that, although failed, do not stop the system from operating, remain failed for a long time. Hence, their MDT per failure is bigger then their Repair Time.
- Conversely, if a Ceramic Gap fails the system will be out of service. That's why, the Ceramic Gap MDT per failure is the same as its repair time.

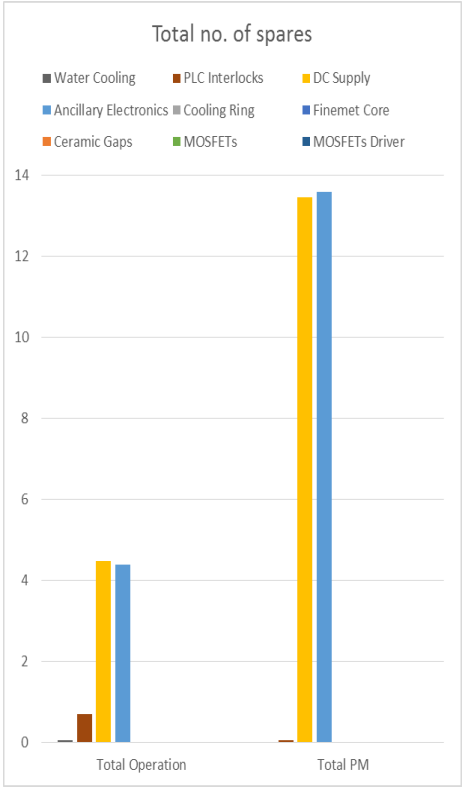


Results – PSB RF **spares** predictions



Spare	Operation	PM	**Total**
MOSFETs Driver	0	0	**0**
MOSFETs	0	0	**0**
Ceramic Gaps	0.003	0	**0.003**
Finemet Core	0.005	0.014	**0.019**
Cooling ring	0	0.004	**0.004**
Ancillary Electronics	4.4	13.6	**18**
DC Supply	4.5	13.5	**18**
PLC Interlocks	0.7	0.07	**0.77**
Water Cooling	0.06	0.006	**0.066**

- One can derive from this pictures the number of spares needed.
- Predictions on maintenance cost and required personal could be done.



Conclusions

- The RF system mean **availability** is evaluated as **99.89%**.
- The expected number of times the RF **System will fail** during one operational year is about **one.**
- **DC Supply** and **Ancillary Electronics** are the components **contributing more to RF system downtime**.
- PLC Interlocks failures are also contributing to RF system downtime.
- The **expected number of spares needed** in one operational year:

Ancillary Electronics	18
DC Supply	18
PLC Interlocks	1

- The **impact of components failures on the PSB RF System is minor due to the implemented redundancy**.
- Predictions on maintenance cost and required personal could be done.

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Analytical Availability/Reliability model

- Calculations based on Boolean system probability theory (to model system dependencies).
- Components failures follow an exponential distribution.
- Bottom to top approach: system availability function from components availability functions.

Planned Maintenance phases not considered/modelled!

Solution: Consider the analytical results obtained at time t=2190h (3 months), why?

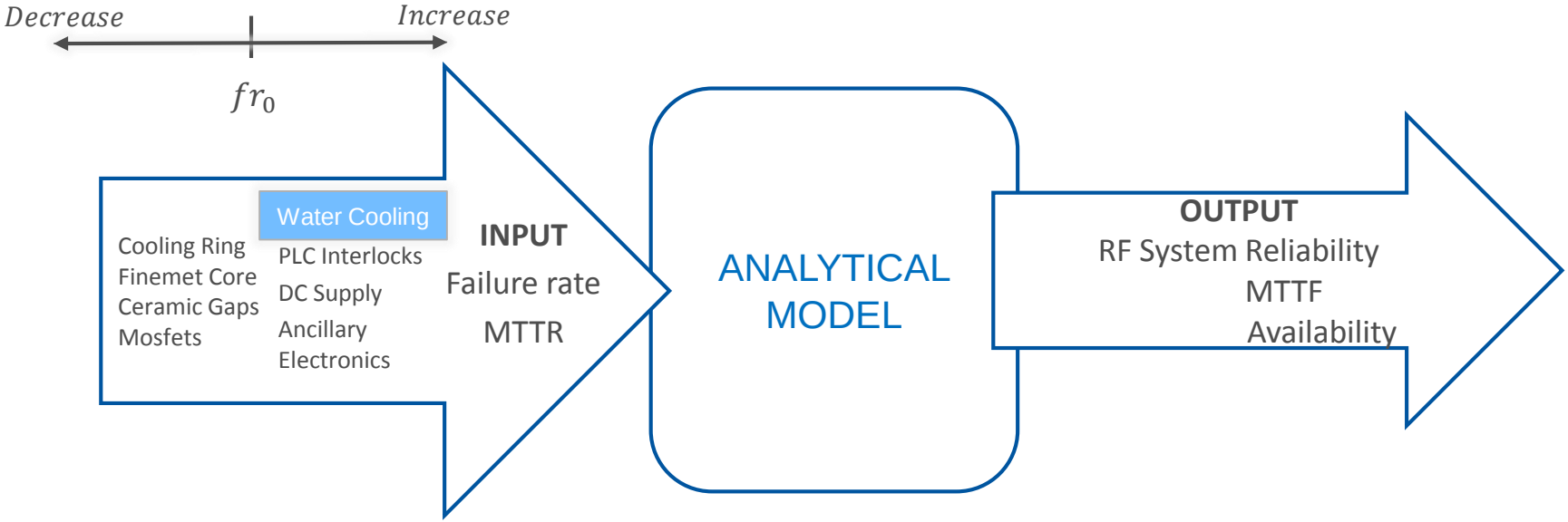
- As it is defined, the system is as good as new after each PM.
- PM time is not considered as downtime, hence, does not affect availability.

This way the results obtained at t=3 months can be compared with the ones obtained from Isograph.

Analytical Availability/Reliability model

Sensitivity analysis – One-at-a-time

Moving one component failure rate and keeping the others at their nominal values to see the effect this produces on the output (Availability and Reliability numbers for the RF System) .



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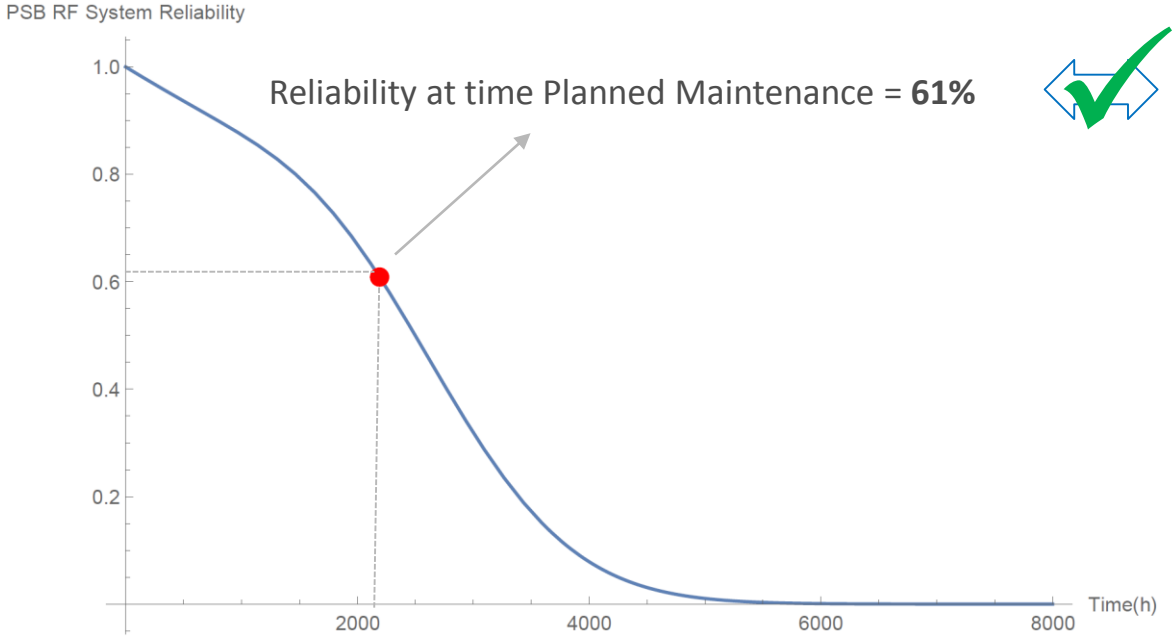
Preliminary results – **System Reliability**

Reliability = Survival probability, probability of the system to perform its required function.
= **Probability that no intervention has to be done.**



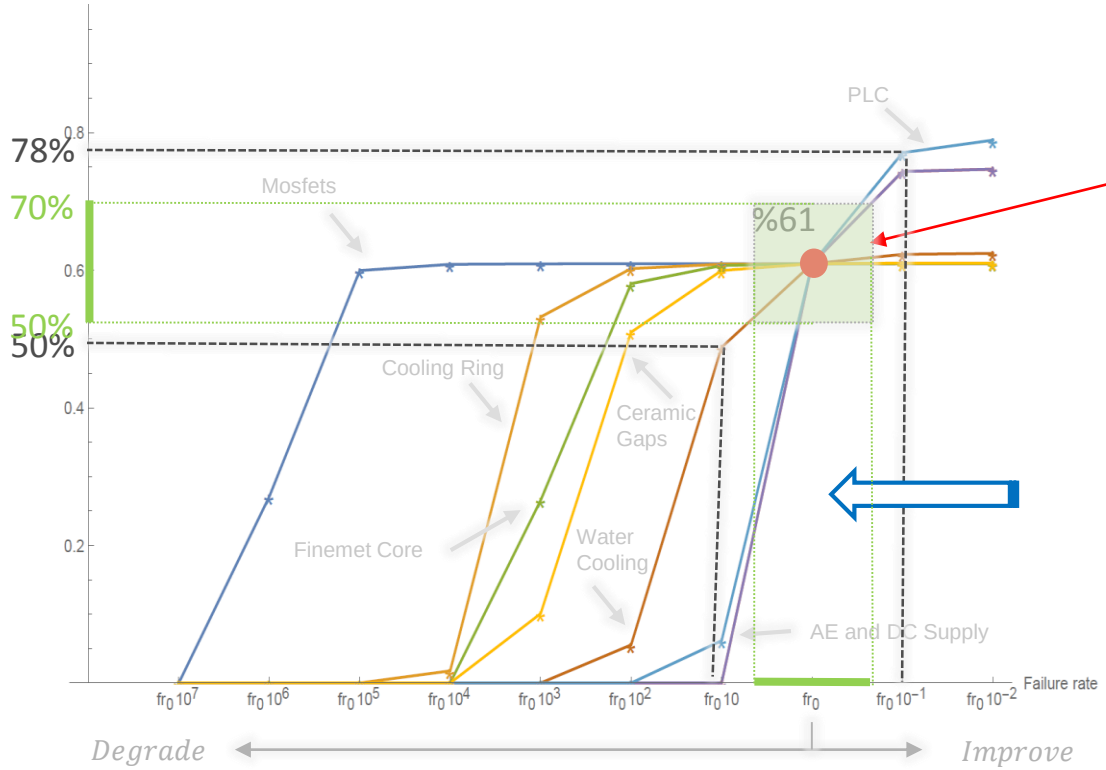
Results from simulations

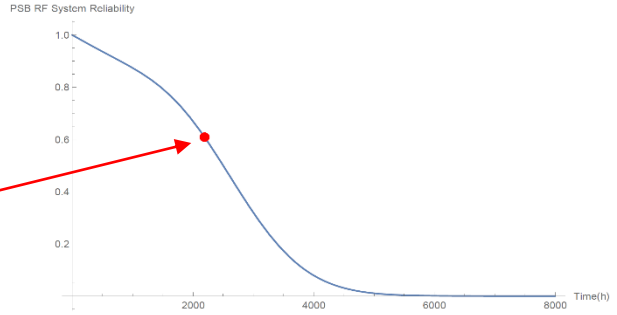
1.078 failures in 3 Operational periods

Failure probability $\approx \frac{1.078}{3} \approx$ 36%

Reliability $\approx \%100 - \%36 \approx \mathbf{64}\%$

Preliminary results – **System Reliability sensitivity to components failure rates**





- Components with more impact in System Reliability:
  - Ancillary Electronics
  - DC Supply
  - PLC Interlocks
  - Water Cooling
- Mosfets have very small impact
- Increase in AE, DC and PLC MTTF, increases System Reliability significantly .

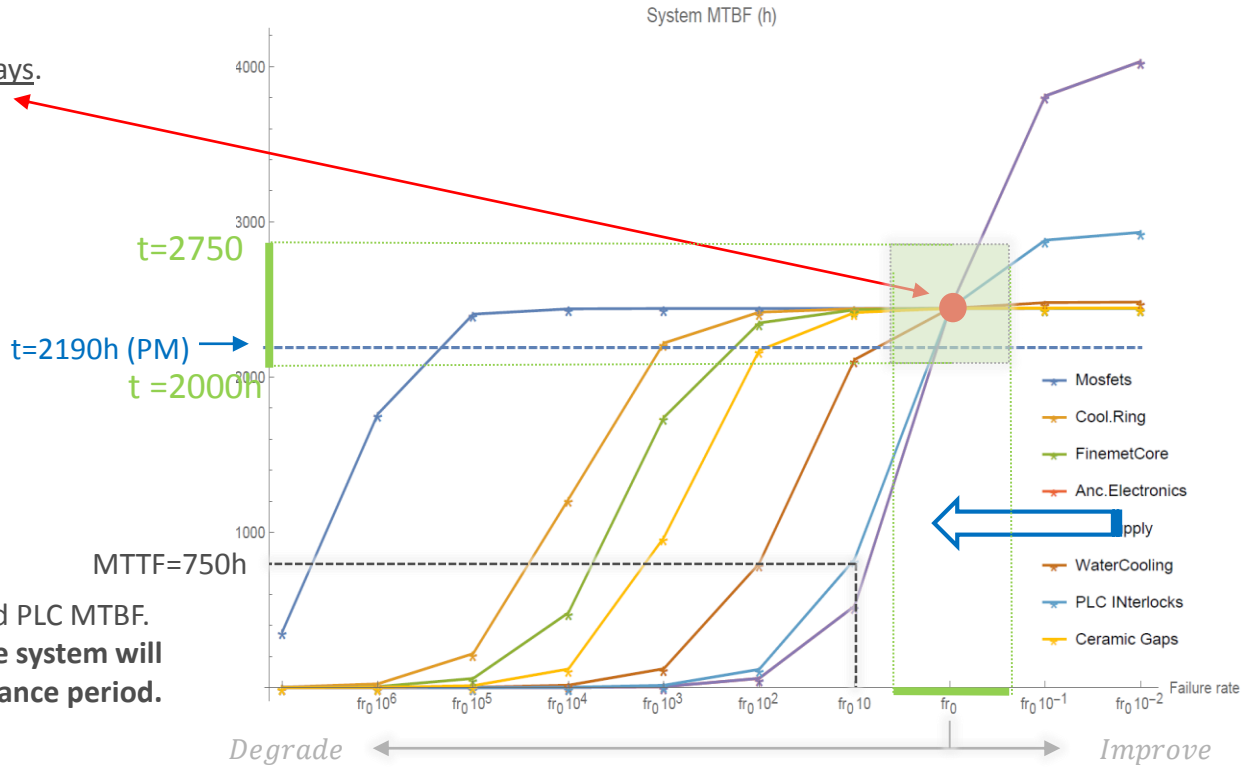
Preliminary results – **System Mean Time To Failure**

- MTTF of the System is 2442 h, i.e.,

The system will probably fail almost <u>each 102 days</u>.

Just after Planned Maintenance !

System MTBF sensitivity to components failure rates

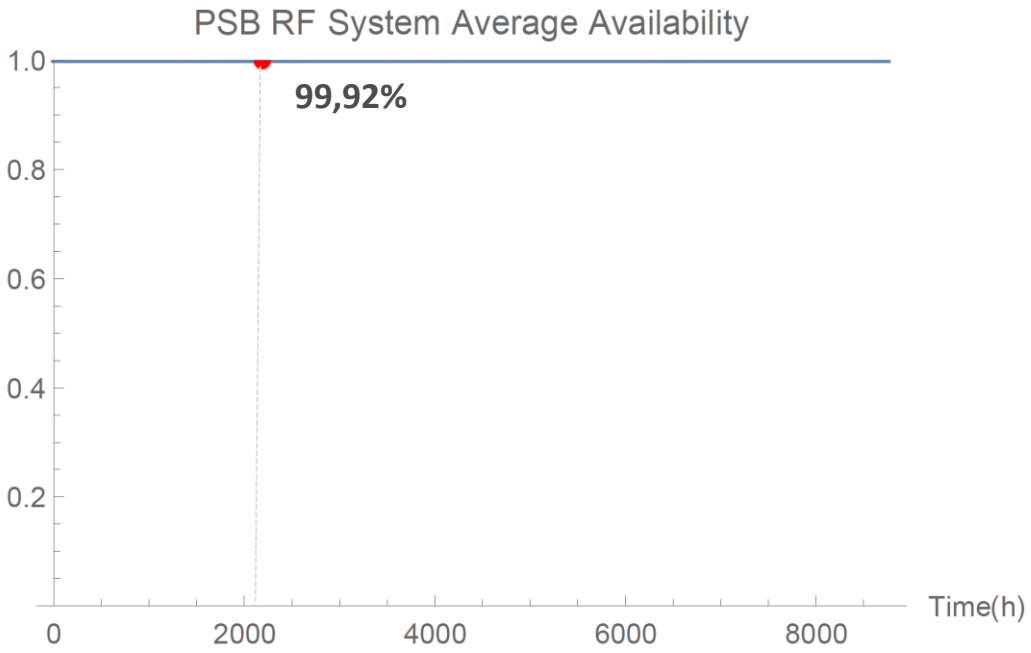


- Special attention must be given to AE, DC and PLC MTBF.

If AE, DC and PLC MTTF is 10 times smaller, the system will probably fail before entering Planned Maintenance period.

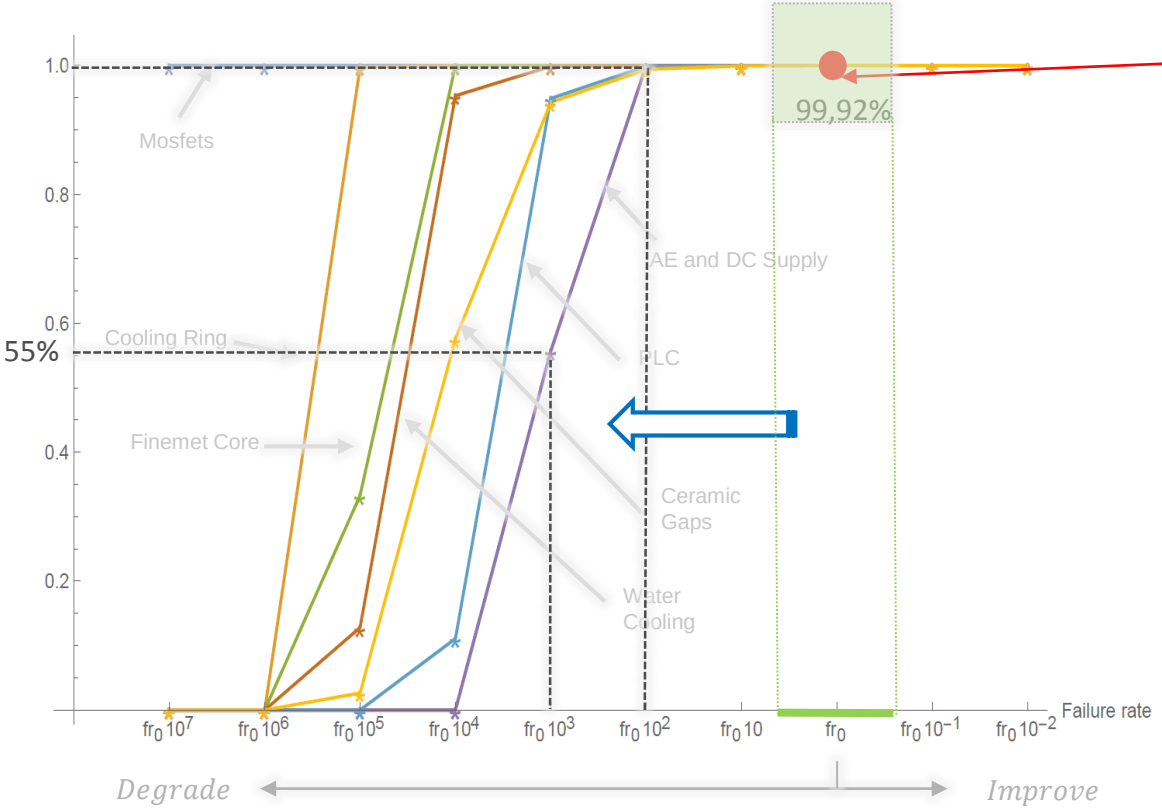
Preliminary results – **System Availability**

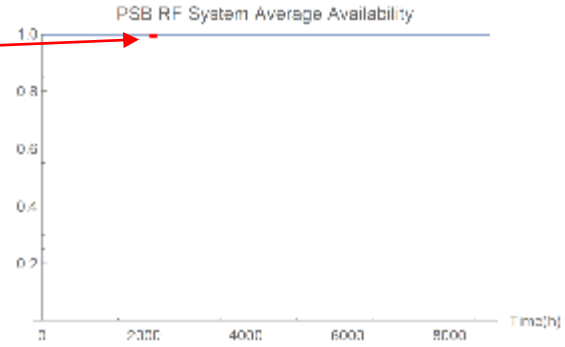
Availability = Fraction of time that can be used for production



Results from simulations
99,89%

Preliminary results – **System Availability sensitivity to components failure rates**





Components with more impact in System Availability:

- Ancillary Electronics
- DC Supply
- PLC Interlocks

Conclusions

- The RF system mean **availability** is evaluated as **%99.92**. (same as obtained from Isograph)
- The **components contributing more to system unavailability** are the same obtained from simulations:

  - **Ancillary Electronics**
  - **DC Supply**
  - **PLC Interlocks**

- Preliminary results. **Further development and verification** needed.
- **Faster method for availability calculations**.

Thanks for your attention!

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Changing assumptions

CORRECTIVE MAINTENANCE:
Maintenance done when the RF system is not available any more due to components failures.

+++ DC Supply, Ancillary electronics and PLC Interlocks are repaired immediately when they fail.

Results – PSB RF System Availability predictions

Before

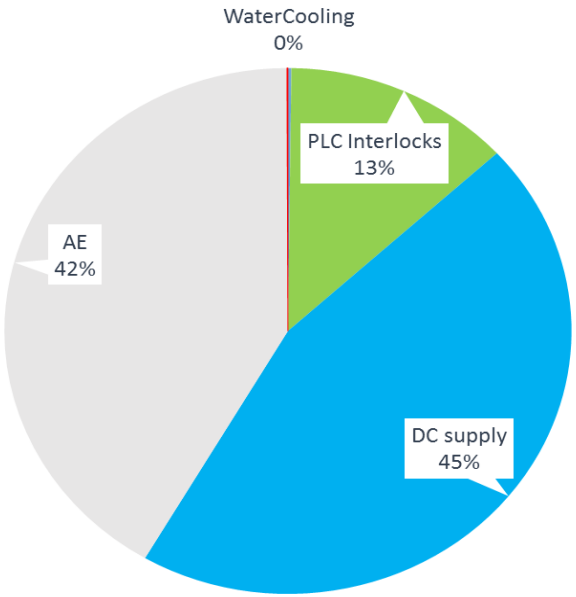
No. of system failures	Downtime (h)	MTBO(h)	MTTR(h)	Mean Availability	Availability at Lifetime
1.077	**6.7**	**6234.3**	**6.2**	**99. 9%**	100%

DC, AE and PLC repairable during Operation

No. of system failures	Downtime (h)	MTBO(h)	MTTR(h)	Mean Availability	Availability at Lifetime
0.05	**0.405**	**131647**	**7.95**	**99. 99%**	100%

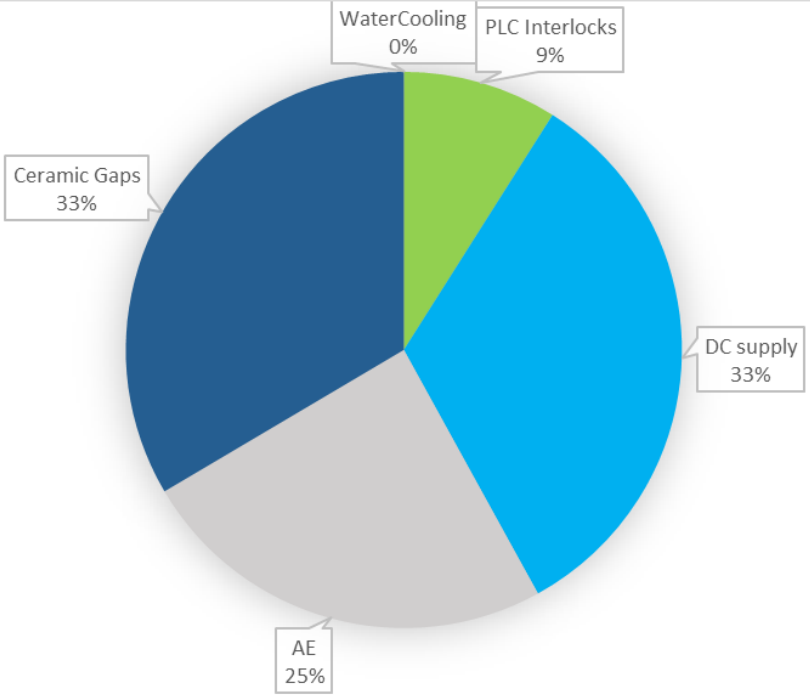
Results -Downtime Contributors

Before



System Downtime Contributors

DC, AE and PLC repairable during Operation



Results – PSB RF System **components** Availability predictions

Before

Component	No. of failures	MDT per failure (h)	MTTR
MOSFETs Driver	0	0	6
MOSFETs	0	0	6
Ceramic Gaps	0.003	72	72
Finemet Core	0.02	1079.3	72
Cooling ring	0.004	980.6	72
Ancillary Electronics	**18**	**954.1**	6
DC Supply	**18**	**954.1**	6
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Water Cooling	0.06	240.2	6

DC, AE and PLC repairable during Operation

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MOSFETs Driver	0	0	6
MOSFETs	0	0	6
Ceramic Gaps	0.002	72	72
Finemet Core	0.02	1211.5	72
Cooling ring	0.004	1145.2	72
Ancillary Electronics	**18**	**6**	6
DC Supply	**18**	**6**	6
PLC Interlocks	**0.67**	**6**	6
Water Cooling	0.02	370.38	6